

WHAT IS CLAIMED IS:

1. A magnetoresistive element, comprising:
a magnetoresistive film; and
a pair of electrodes electrically connected to
5 upper and lower surfaces of the magnetoresistive film,
respectively, so as to flow a sense current in a
direction substantially perpendicular to a plane of the
magnetoresistive film,
in which the magnetoresistive film comprises:
10 a first magnetization free layer of a
ferromagnetic film whose magnetization direction is
changed in response to the external magnetic field,
a second magnetization free layer of a
ferromagnetic film whose magnetization direction is
15 changed in response to the external magnetic field,
a first magnetization pinned layer of
a ferromagnetic film whose magnetization direction is
substantially pinned in one direction,
a second magnetization pinned layer of
20 a ferromagnetic film whose magnetization direction is
substantially pinned in one direction,
a third magnetization pinned layer of
a ferromagnetic film whose magnetization direction is
substantially pinned in one direction,
25 a fourth magnetization pinned layer of
a ferromagnetic film whose magnetization direction is
substantially pinned in one direction,

a first nonmagnetic intermediate layer formed between the first magnetization free layer and the first magnetization pinned layer,

5 a second nonmagnetic intermediate layer formed between the first magnetization free layer and the second magnetization pinned layer,

a third nonmagnetic intermediate layer formed between the second magnetization free layer and the third magnetization pinned layer, and

10 a fourth nonmagnetic intermediate layer formed between the second magnetization free layer and the fourth magnetization pinned layer,

the second magnetization pinned layer and the third magnetization pinned layer being formed between
15 the second nonmagnetic intermediate layer and the third nonmagnetic intermediate layer;

the pinned direction of magnetization of the first magnetization pinned layer is substantially parallel to the pinned direction of magnetization of the second
20 magnetization pinned layer, the pinned direction of magnetization of the third magnetization pinned layer is substantially parallel to the pinned direction of magnetization of the fourth magnetization pinned layer, and the pinned direction of magnetization of the second
25 magnetization pinned layer is substantially antiparallel to the pinned direction of magnetization of the third magnetization pinned layer.

2. The magnetoresistive element according to claim 1, wherein, when the magnetization pinned layers are classified into two sets consisting of a first set of the first magnetization pinned layer and the second magnetization pinned layer and a second set of the third magnetization pinned layer and the fourth magnetization pinned layer, each of the magnetization pinned layers for one set is formed of a single ferromagnetic layer or is formed of a stack of an odd number of ferromagnetic layers and nonmagnetic layers, and each of the magnetization pinned layers for the other set is formed of a stack of an even number of ferromagnetic layers and nonmagnetic layers.

3. The magnetoresistive element according to claim 1, wherein,

the magnetization of the first magnetization pinned layer is pinned by exchange coupling with a first ferromagnetic layer;

the magnetization of each of the second magnetization pinned layer and the third magnetization pinned layer is pinned by exchange coupling with a second antiferromagnetic layer; and

the magnetization of the fourth magnetization pinned layer is pinned by exchange coupling with a third antiferromagnetic layer.

4. The magnetoresistive element according to claim 1, wherein the pair of electrodes electrically

connected to upper and lower surfaces of the magnetoresistive film, respectively, provides a differential output.

5 5. The magnetoresistive element according to claim 1, wherein a gap between the first and second magnetization free layers ranges from 1 nm to 50 nm.

 6. The magnetoresistive element according to claim 1, wherein at least one layer of the first to fourth nonmagnetic intermediate layers contains
10 an oxide.

 7. The magnetoresistive element according to claim 6, wherein the nonmagnetic intermediate layer containing the oxide has a thickness ranging from 0.5 nm to 5 nm.

15 8. A magnetoresistive element, comprising:
 a magnetoresistive film; and
 a pair of electrodes electrically connected to upper and lower surfaces of the magnetoresistive film, respectively, so as to flow a sense current in
20 a direction substantially perpendicular to a plane of the magnetoresistive film,

 in which the magnetoresistive film comprises:
 a first magnetization free layer of
 a ferromagnetic film whose magnetization direction is
25 changed in response to the external magnetic field,
 a second magnetization free layer of
 a ferromagnetic film whose magnetization direction is

changed in response to the external magnetic field,

a first magnetization pinned layer of
a ferromagnetic film whose magnetization direction is
substantially pinned in one direction,

5 a second magnetization pinned layer of
a ferromagnetic film whose magnetization direction is
substantially pinned in one direction,

a first nonmagnetic intermediate layer formed
between the first magnetization free layer and the
10 first magnetization pinned layer, and

a second nonmagnetic intermediate layer formed
between the second magnetization free layer and the
second magnetization pinned layer,

the first magnetization pinned layer and the
15 second magnetization pinned layer being formed between
the first nonmagnetic intermediate layer and the second
nonmagnetic intermediate layer;

the pinned direction of magnetization of the first
magnetization pinned layer is substantially
20 antiparallel to the pinned direction of magnetization
of the second magnetization pinned layer, and the
magnetization of each of the first magnetization pinned
layer and the second magnetization pinned layer is
pinned by exchange coupling with one antiferromagnetic
25 layer.

9. The magnetoresistive element according to
claim 8, wherein one of the first magnetization pinned

layer and the second magnetization pinned layer is formed of a single ferromagnetic layer or is formed of a stack of an odd number of ferromagnetic layers and nonmagnetic layers, and the other magnetization pinned
5 layer is formed of a stack of an even number of ferromagnetic layers and nonmagnetic layers.

10. The magnetoresistive element according to claim 8, wherein the pair of electrodes electrically connected to upper and lower surfaces of the
10 magnetoresistive film, respectively, provides a differential output.

11. The magnetoresistive element according to claim 8, wherein a gap between the first and second magnetization free layers ranges from 1 nm to 50 nm.

15 12. The magnetoresistive element according to claim 8, wherein at least one layer of the first and second nonmagnetic intermediate layers contains an oxide.

20 13. The magnetoresistive element according to claim 12, wherein the nonmagnetic intermediate layer containing the oxide has a thickness ranging from 0.5 nm to 5 nm.

14. A magnetic head comprising the magnetoresistive element according to claim 1.

25 15. A magnetic recording/reproducing apparatus, comprising:

the magnetic head according to claim 14; and

a perpendicular magnetic recording medium.

16. A magnetic head comprising the
magnetoresistive element according to claim 8.

17. A magnetic recording/reproducing apparatus,
5 comprising:

the magnetic head according to claim 16; and
a perpendicular magnetic recording medium.